W and Z boson production at LHCb

Karol Hennessy

on behalf of the LHCb Collaboration

UNIVERSITY OF LIVERPOOL

Overview

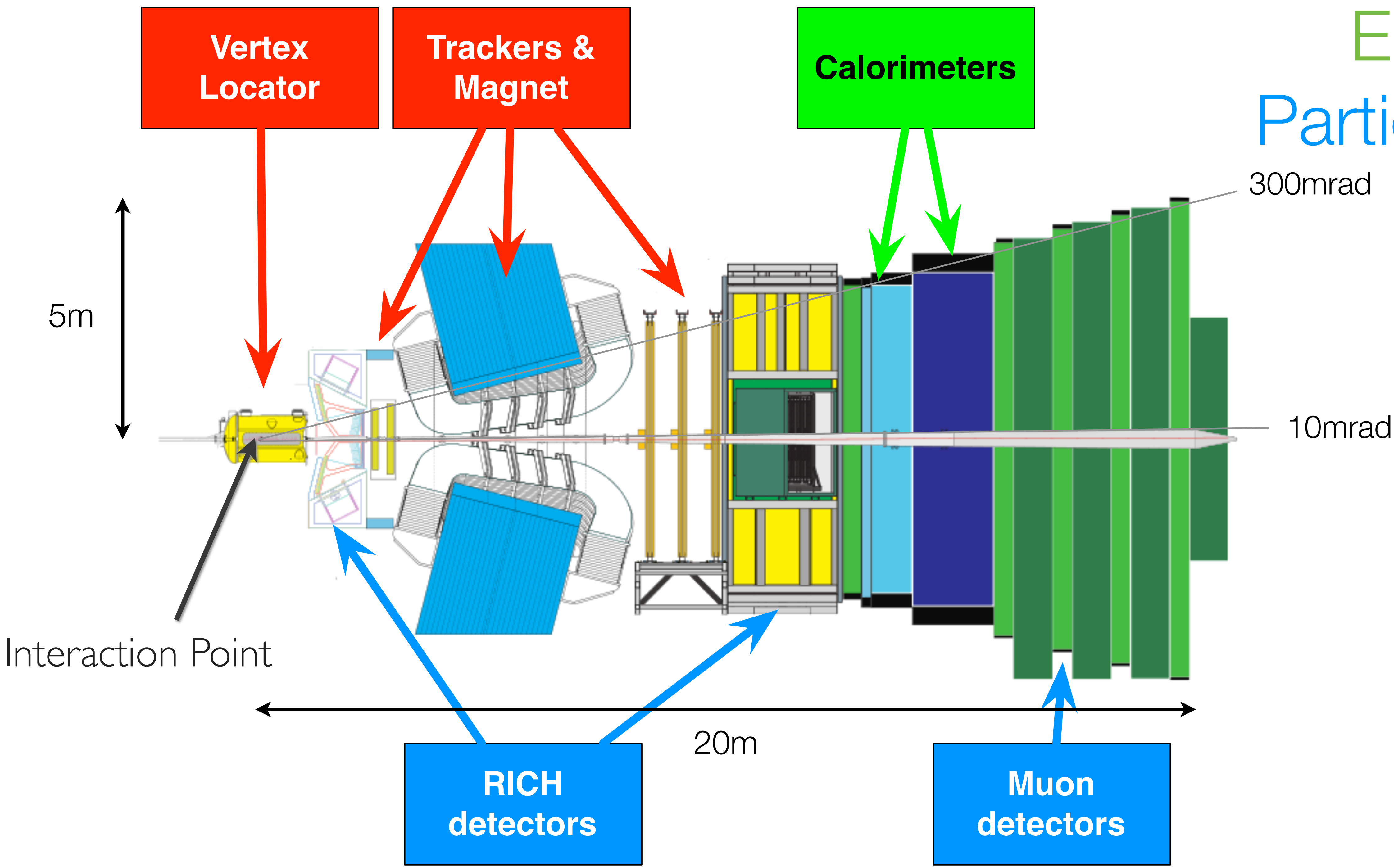
- Motivation
- $Z \rightarrow \mu\mu$ selection
- $W \rightarrow \mu\nu$ selection
- Efficiencies
- Cross-sections
- Summary

LHCb

- LHCb is a flavour physics detector, designed to detect decays of b- and c-hadrons for the study of CP violation and rare decays.
- Precision experiment with excellent spatial resolution and particle ID making it ideal for tests of the Standard Model
- Pseudorapidity range
  - LHCb $1.9<\eta<4.9$
  - ATLAS/CMS $|\eta|<2.5$
- Muon momentum reconstruction p>3GeV/c
- Luminosity 2010 - 37.7pb^{-1} on tape; 16.5±1.7pb^{-1} used in this analysis

LHCb

Momentum
Energy
Particle ID

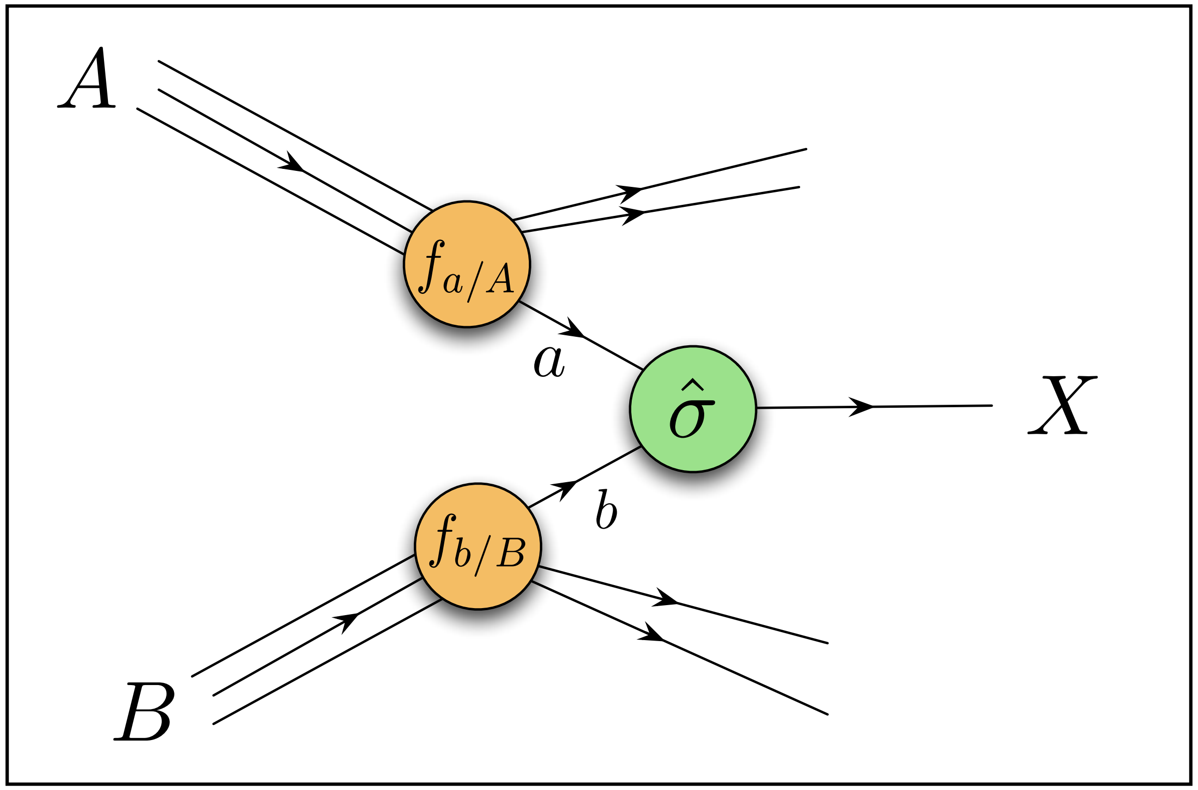


PDFs

$$\sigma_{AB\to X} = \int dx_a dx_b \underbrace{f_{a/A}\left(x_a, Q^2\right) f_{b/B}\left(x_b, Q^2\right)}_{\text{PDFs}} \underbrace{\hat{\sigma}_{ab\to X}}_{\text{Calculable at NNLO}}$$

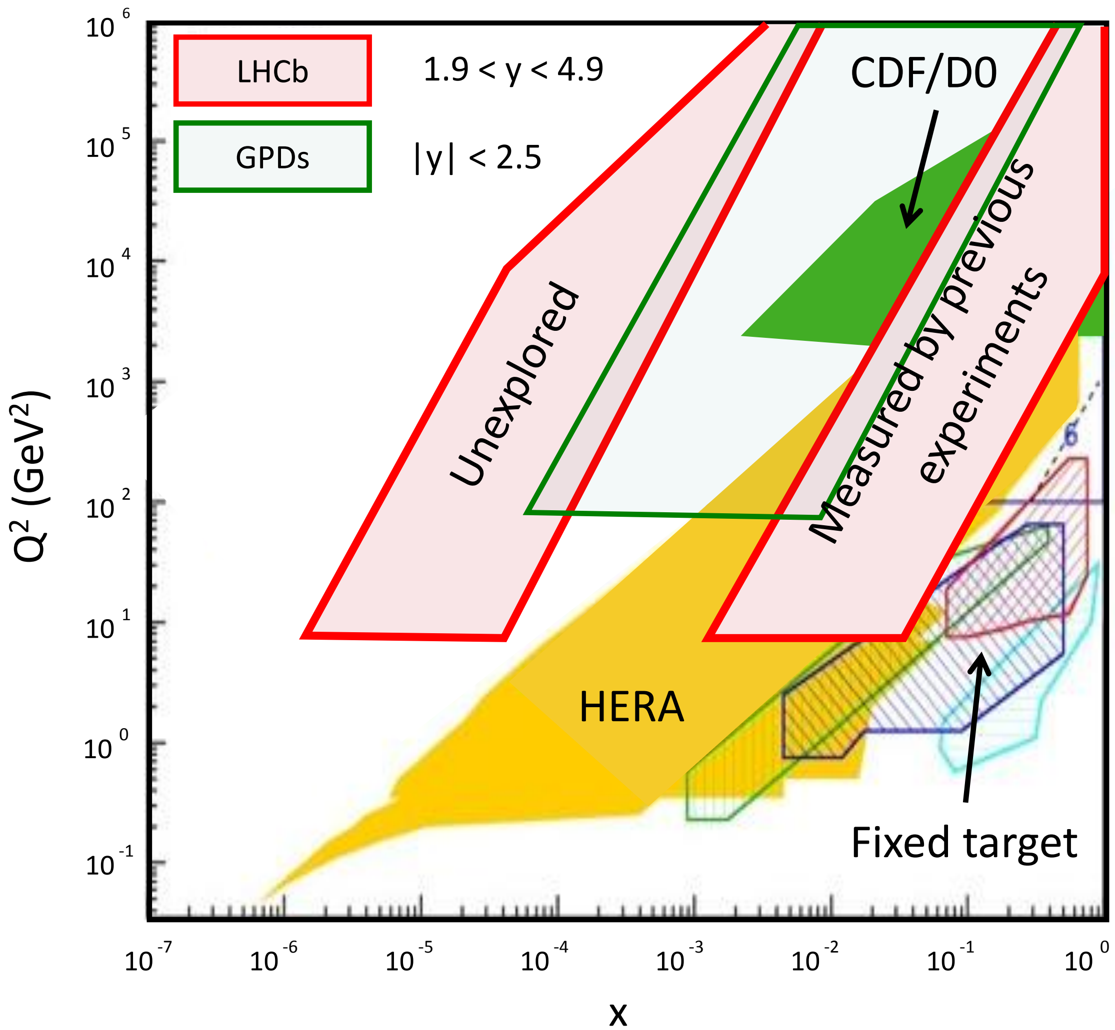
PDFs
Non - perturbative

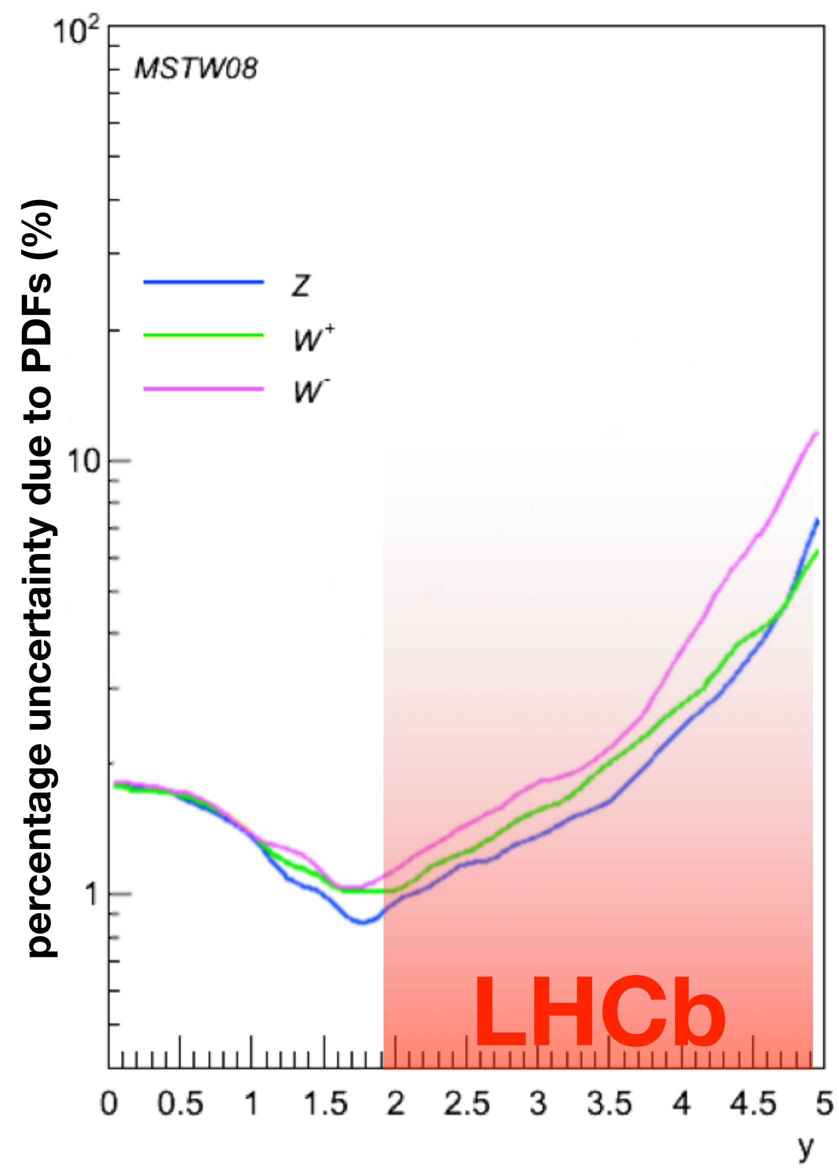
Calculable at NNLO
perturbative



- *Dominant uncertainty from PDFs*

LHCb Measurement





- Region of high Q^2 and low-x unexplored
- Measurable at LHCb with W/Z

Ratios

- Many systematics cancel in Ratios

$$A_W = \frac{d\sigma(W^+) - d\sigma(W^-)}{d\sigma(W^+) + d\sigma(W^-)}$$

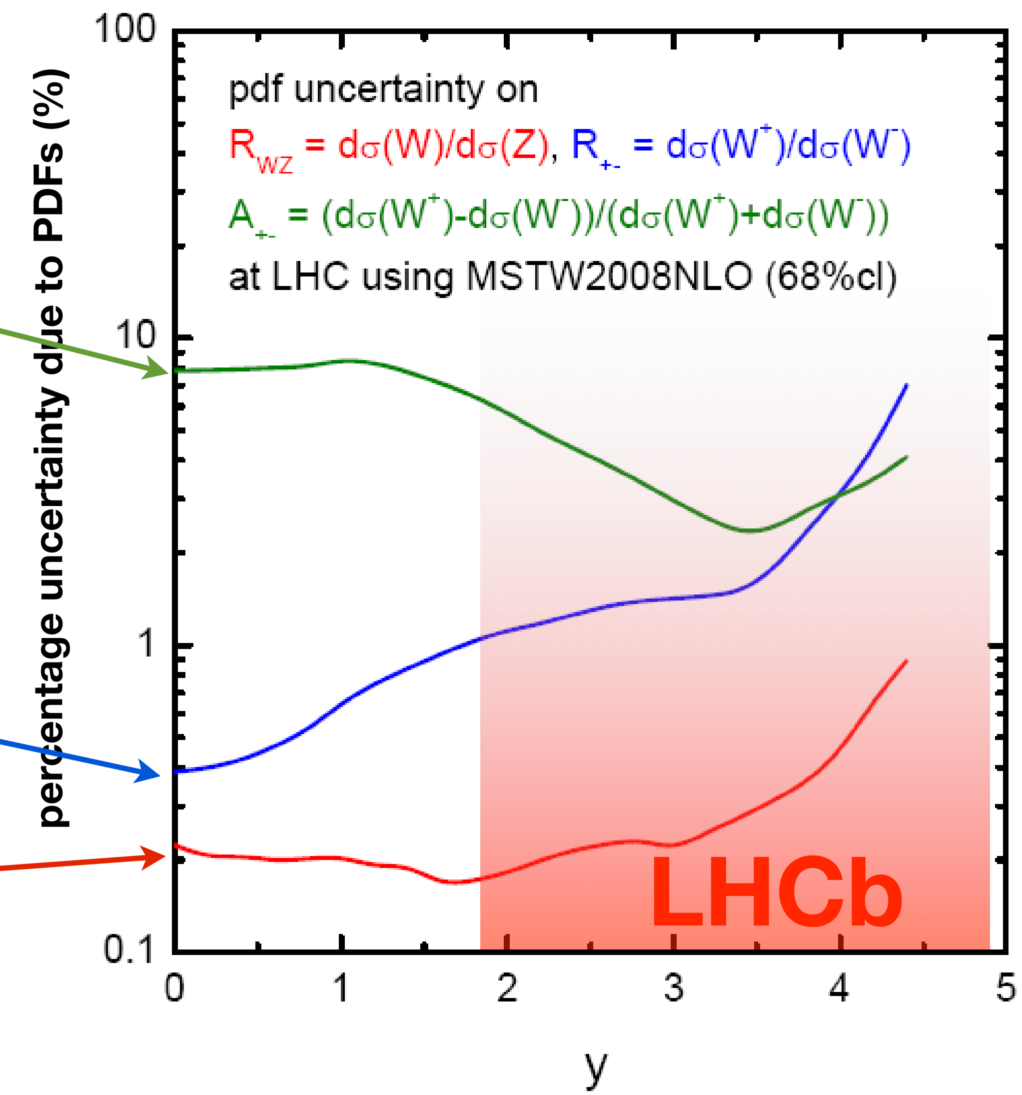
- tests valence u and d difference

$$R_{\pm} = \frac{d\sigma(W^+)}{d\sigma(W^-)}$$

- tests ratio d/u

$$R_{WZ} = \frac{d\sigma(W^{\pm})}{d\sigma(Z)}$$

- tests SM predictions

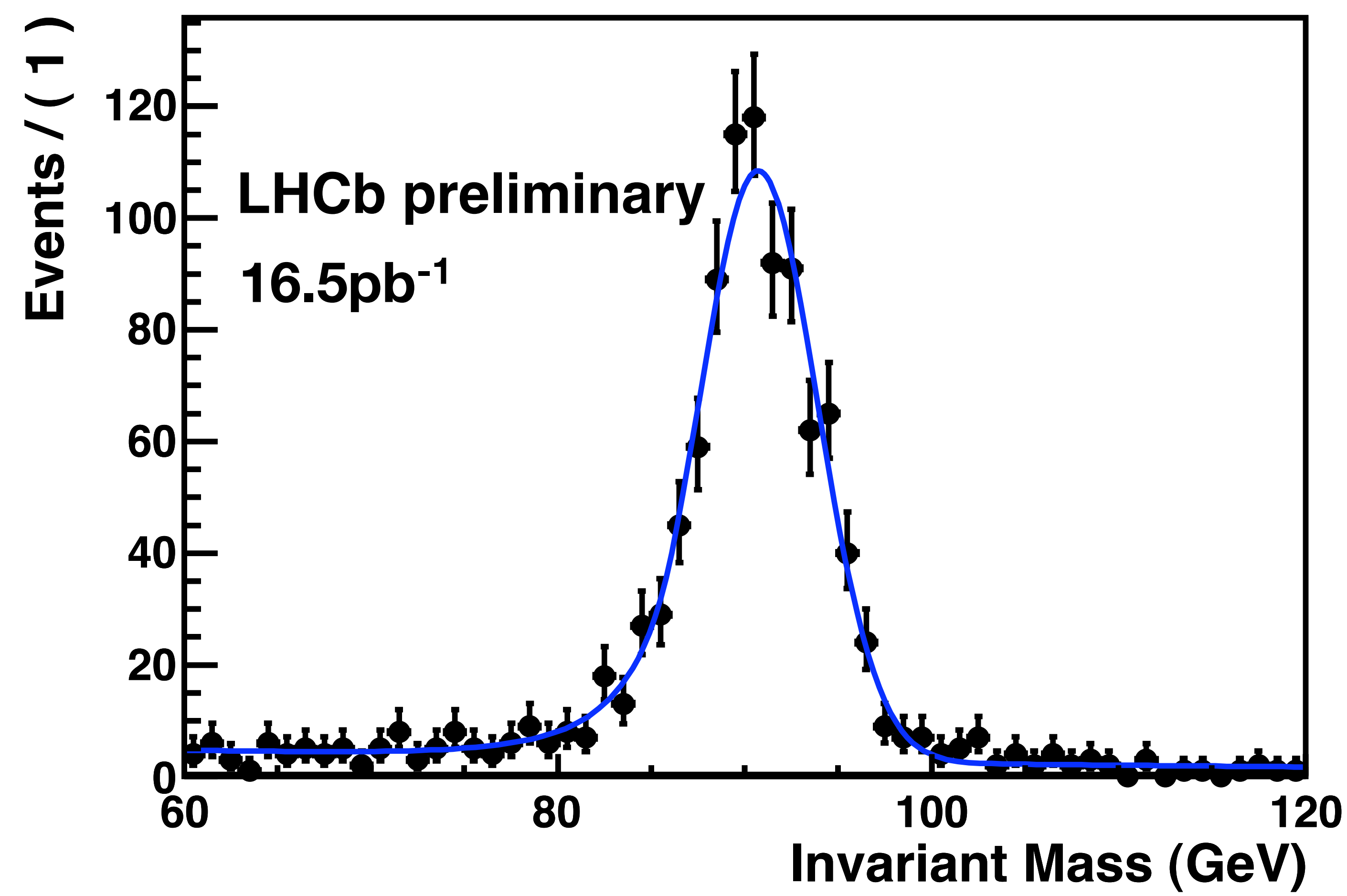


$Z \rightarrow \mu^+\mu^-$

Trigger:	Single μ	p_T>10GeV/c
Reconstruction:	2 μ	p_T>20GeV/c
Selection:	Pseudorapidity of each muon	2.0< η <4.5
	Mass	$81<M_{\mu\mu}<101$GeV/c^2

Backgrounds:	$Z \rightarrow \tau\tau$ (data+MC) (0.2)
	Kπ mis-id (data) (<0.03)
	Heavy Flavour QCD background (data) 1
N^{bkg}	1.2±1.2

N^Z	833



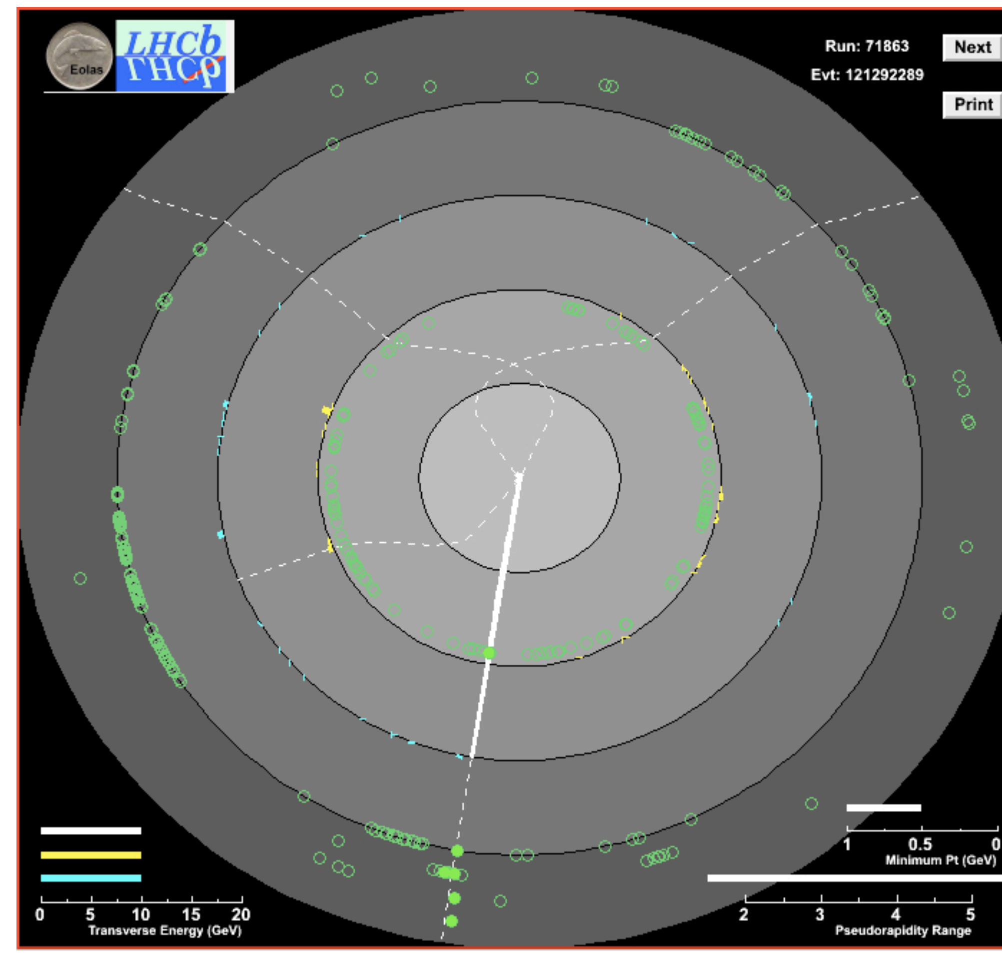
$W^{\pm} \rightarrow \mu^{\pm}\nu$

Trigger:	Single μ	p_T>10GeV/c
Reconstruction:	1μ	p_T>20GeV/c
Selection:	Pseudorapidity	2.0< η <4.5
	IP Signficance	IPsig < 2
	Cone P_T ($R=\sqrt{\Delta\eta^2+\Delta\varphi^2}=0.5$)	ΣP_T<2 GeV/c
	Rest of event	ΣM<20GeV/c^2
		ΣP_T<10GeV/c

Backgrounds:

- $Z \rightarrow \mu\mu$ (MC renormalised by data)
- $Z \rightarrow \tau\tau$ (data+MC)
- $W \rightarrow \tau\nu$ (MC)
- Heavy Flavour QCD background (data)

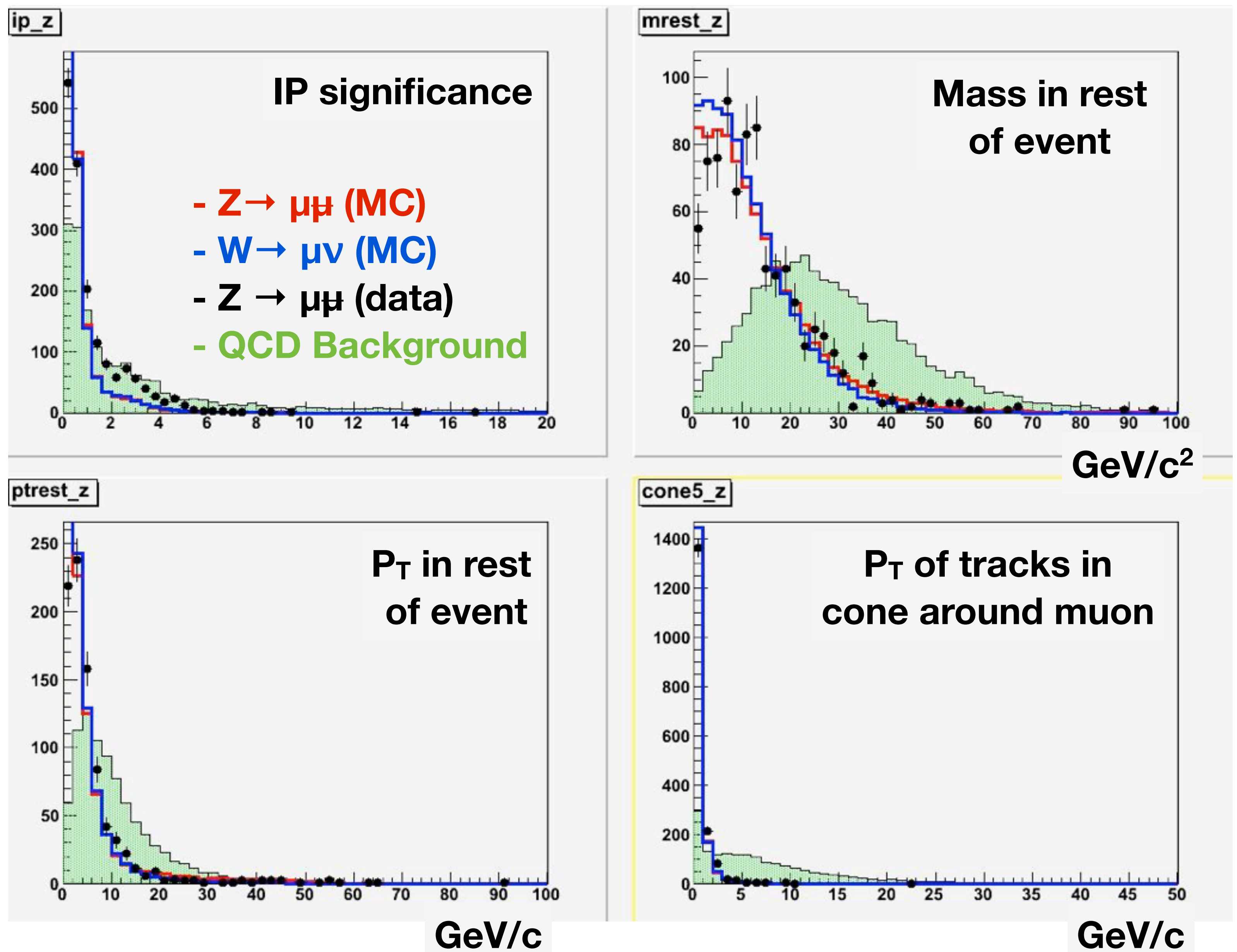
φ-z view



W candidate event

$W^{\pm}$ Selection

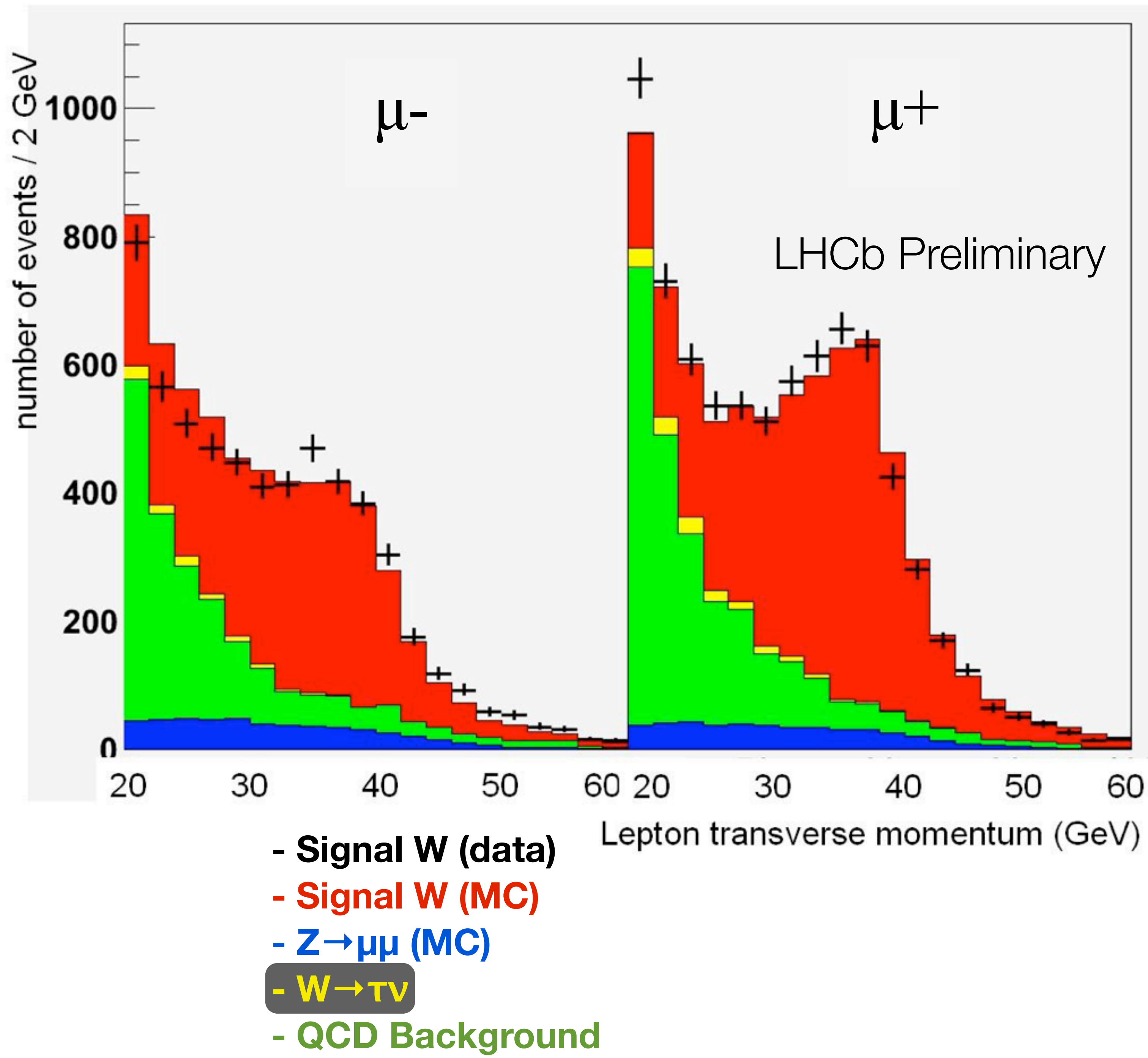
- Estimate W signal using $Z \to \mu\mu$ with one muon masked.
    - MC $Z \to \mu\mu$ and $W \to \mu\nu$ similar distributions
    - Data Z distributions look similar to MC Z
    - Therefore we can model W with Z data
- Reverse cuts on one variable to make background enriched samples and create templates to fit data.
- Determine efficiency and purity from fits.



W$^{\pm}$ Selection

- From template fits
- Total number of events in selection
  - # W+ 7624
  - # W- 5732
- QCD background from fits

	W^{+}	W^{-}
QCD	2194±150	1654±150
N^{W}	4817±165	3480±161



Efficiencies

$$\varepsilon_Z = A_Z \times \varepsilon_Z^{trig} \times \varepsilon_Z^{track} \times \varepsilon_Z^{muon} \times \varepsilon_Z^{sel}$$

1 2 3 4 5

- Determine efficiencies from data

1 LHCb Acceptance - Acceptance 1 by definition - cross-section measured in the forward region with both muons in pseudorapidity $2.0<\eta<4.5$

2 Trigger efficiency

3 Track finding efficiency

4 Muon identification efficiency

5 Selection Efficiency

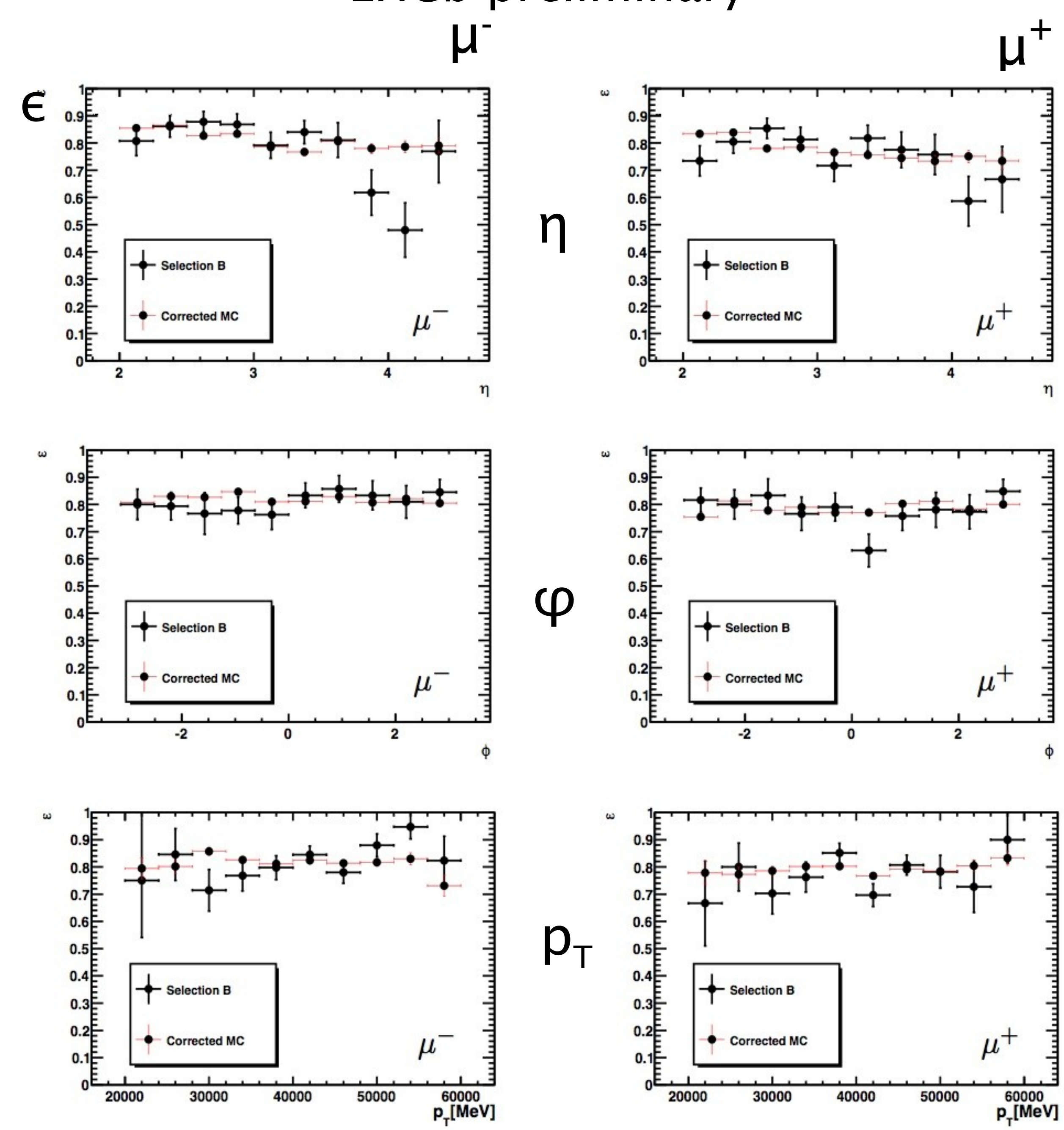
Trigger efficiency

$$\varepsilon_Z = A_Z \times \boxed{\varepsilon_Z^{trig}} \times \varepsilon_Z^{track} \times \varepsilon_Z^{muon} \times \varepsilon_Z^{sel}$$

- Using Single Muon Trigger - P_T>10GeV/c
- Flat in η, φ, P_T
- No charge bias
- Efficiencies include global event cuts

ε_W	72±1%
ε_Z	86±1%

LHCb preliminary



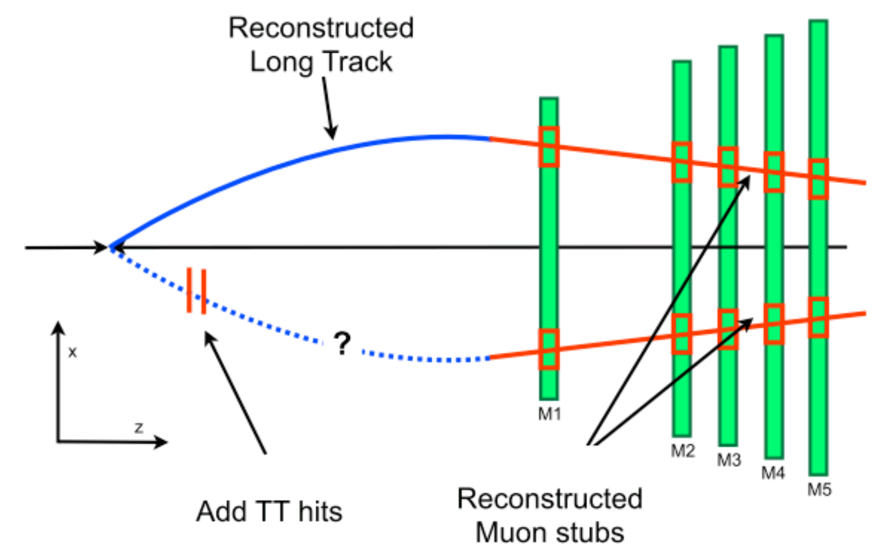
Tracking efficiency

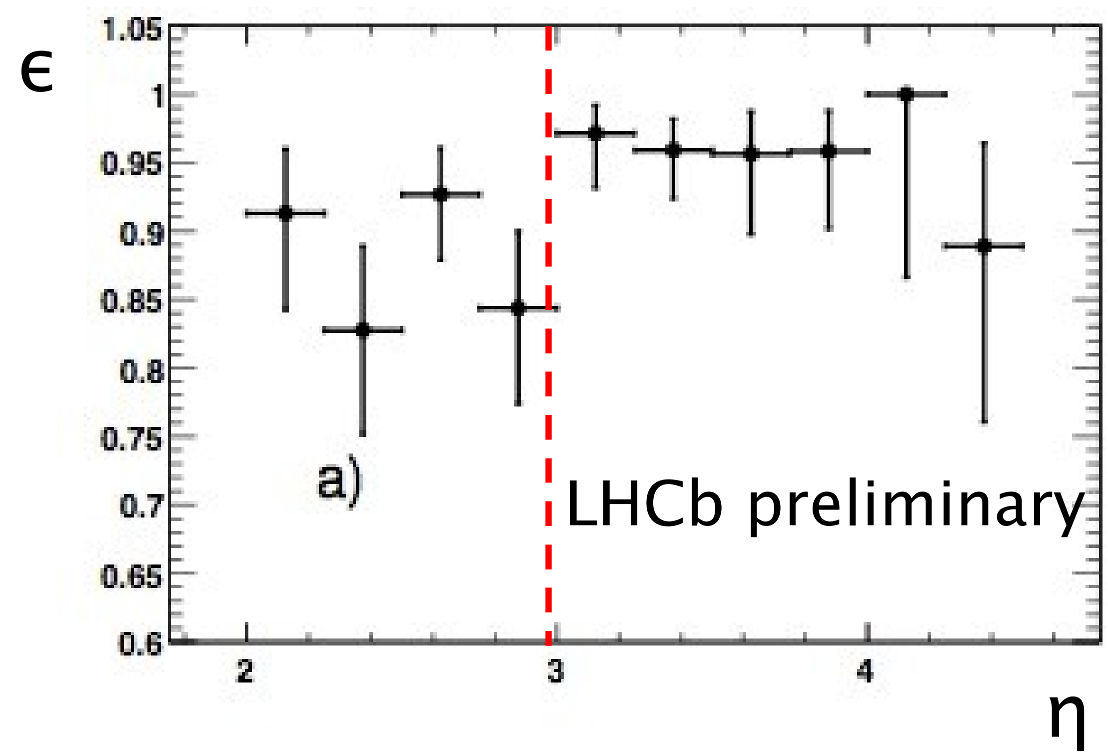
$$\varepsilon_Z = A_Z \times \varepsilon_Z^{trig} \times \boxed{\varepsilon_Z^{track}} \times \varepsilon_Z^{muon} \times \varepsilon_Z^{sel}$$

- Use clean sample of Z events with one muon as tag and other as probe
- Flat in φ, P_T
- Dependence on η - split into two regions:

ε_{W+}	73±3%
ε_{W-}	78±3%
ε_Z	83±3%

Track efficiency from Tag & Probe





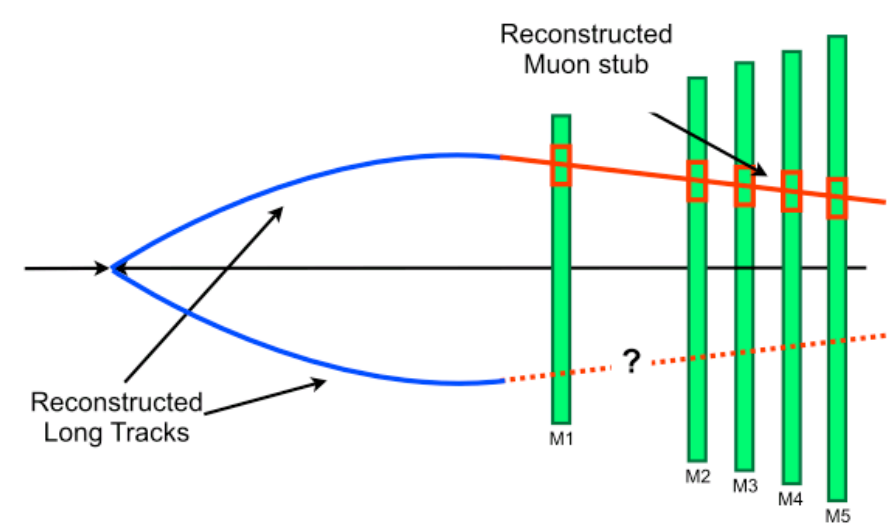
Muon ID efficiency

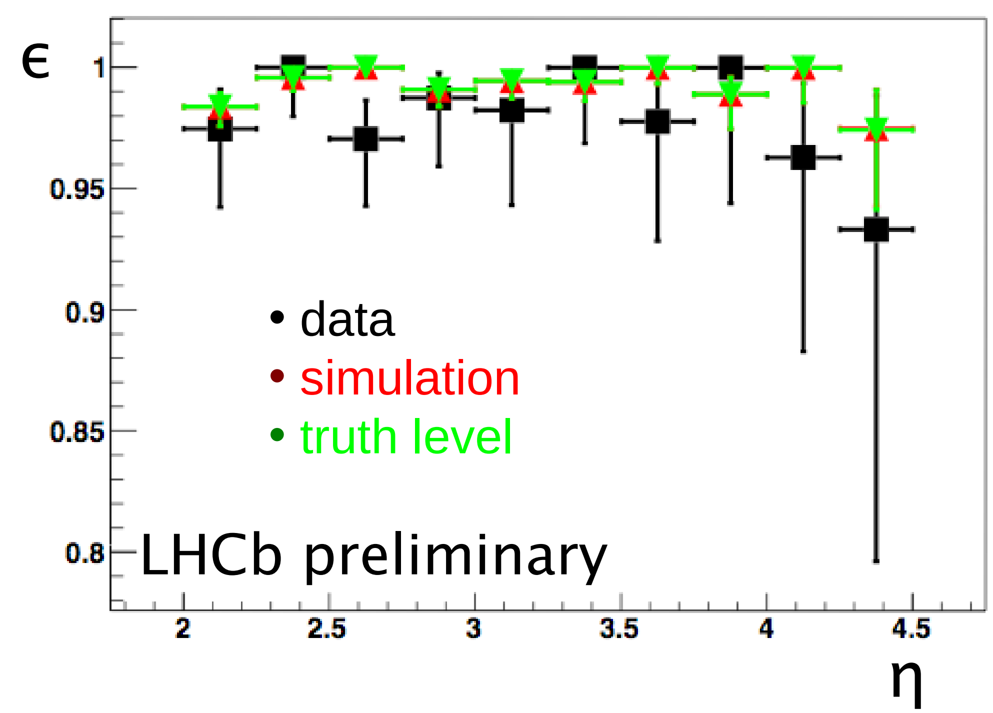
$$\varepsilon_Z = A_Z \times \varepsilon_Z^{trig} \times \varepsilon_Z^{track} \times \boxed{\varepsilon_Z^{muon}} \times \varepsilon_Z^{sel}$$

- Tag and probe method
- Use triggered Z sample with no PID information
- Flat in η, φ, P_T , charge

ε_W	98.2±0.5%
ε_Z	96.5±0.7%

Muon ID from Tag & Probe





Selection efficiency

$$\varepsilon_Z = A_Z \times \varepsilon_Z^{trig} \times \varepsilon_Z^{track} \times \varepsilon_Z^{muon} \times \boxed{\varepsilon_Z^{sel}}$$

- Z selection criteria define the measurement region - $\varepsilon_Z = 1$
- W determined from Z data with one muon removed.

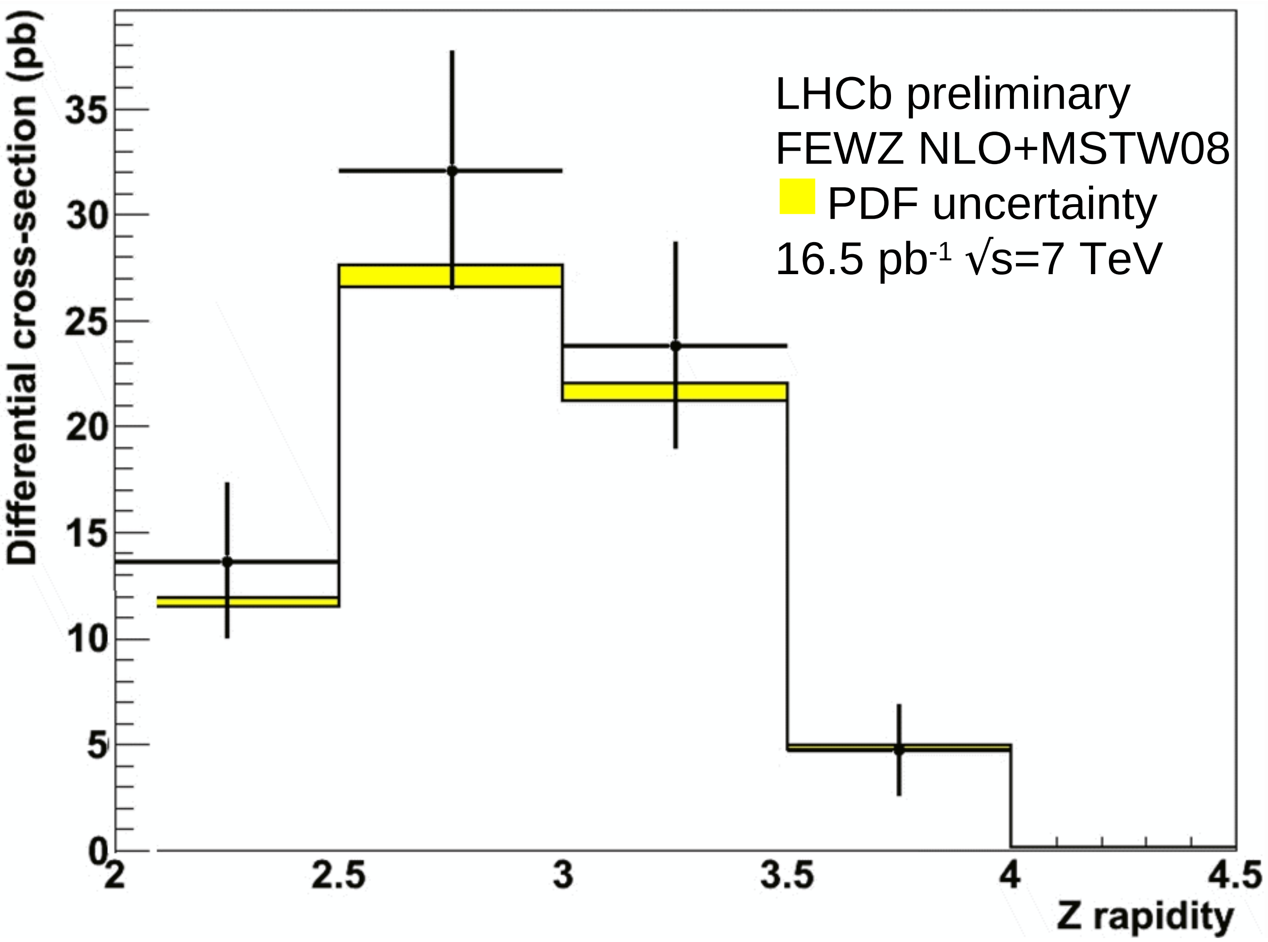
ε_W	55.0±1.0%
ε_Z	100.0%

Z Cross-section

$$\sigma_{Z\to\mu\mu} = \frac{N_Z^{tot} - N_Z^{bkg}}{\varepsilon_Z \cdot \int \mathcal{L}dt}$$

$81<M_{\mu\mu}<101$ GeV/c^2

N^{tot}	833
N^{bkg}	1.2±1.2
A	1.0
ε^{trig}	0.86±0.01
ε^{track}	0.83±0.03
ε^{muon}	0.97±0.01
ε^{sel}	1.0
ε_Z	0.69±0.03
$\int \mathcal{L}dt$	16.5±1.7pb^{-1}



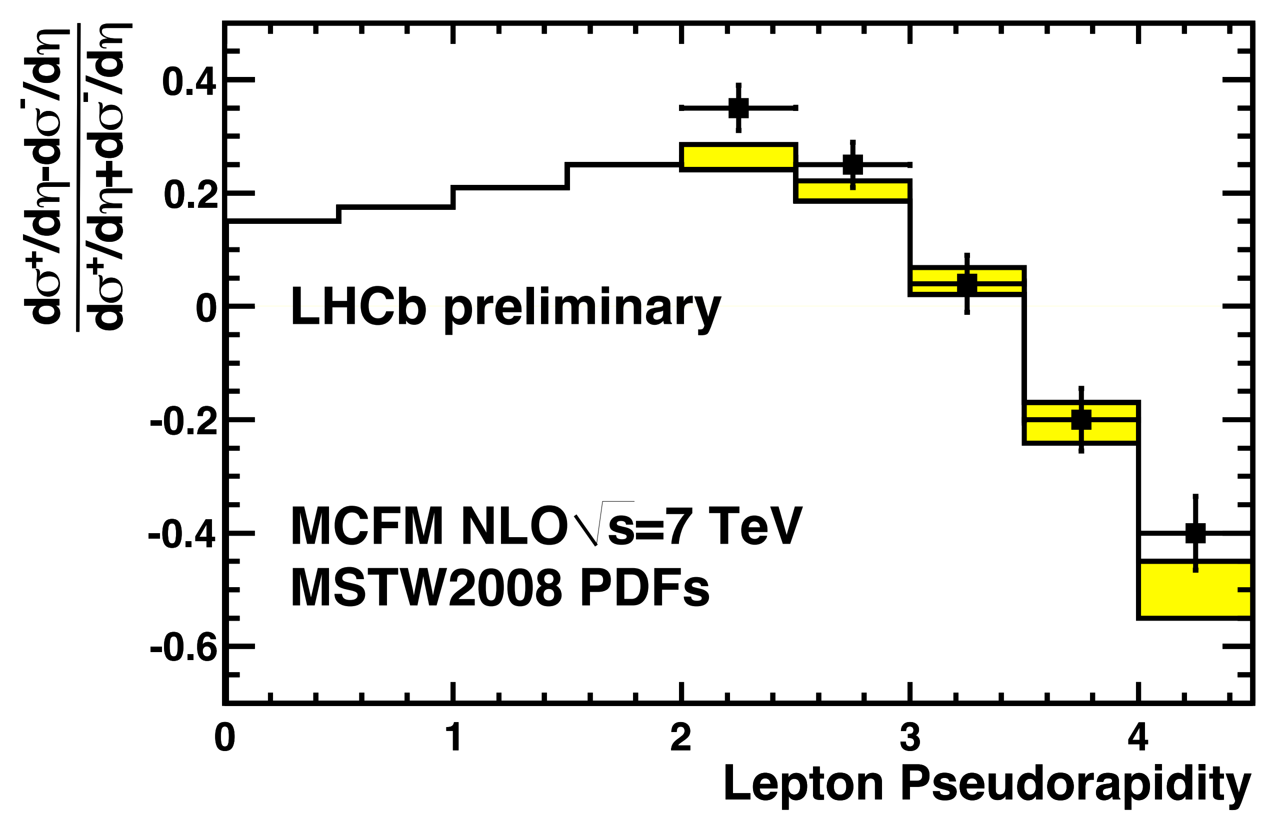
$\sigma_Z \cdot B(Z\to\mu^+\mu^-\ ;\ 2<\eta_\mu<4.5) = 73\pm4\pm7$pb

W± Cross-section

$$\sigma_{W\to\mu\nu} = \frac{N_W^{tot} - N_W^{bkg}}{\varepsilon_W \cdot \int \mathcal{L}dt}$$

	W+	W-
N^{tot}	7624	5723
$W\to\tau\nu$	151	90
$Z\to\tau\tau$	2	2
$Z\to\mu\mu$	460	506
QCD	2194±150	1654±150
N^{W}	4817±165	3480±161
A	1.0	
ε^{trig}	0.73±0.03	
ε^{track}	0.73±0.03	0.78±0.03
ε^{muon}	0.982±0.005	
ε^{sel}	0.55±0.01	
ε_W	0.29±0.01	0.31±0.01
$\int \mathcal{L}dt$	16.5±1.7pb^{-1}	

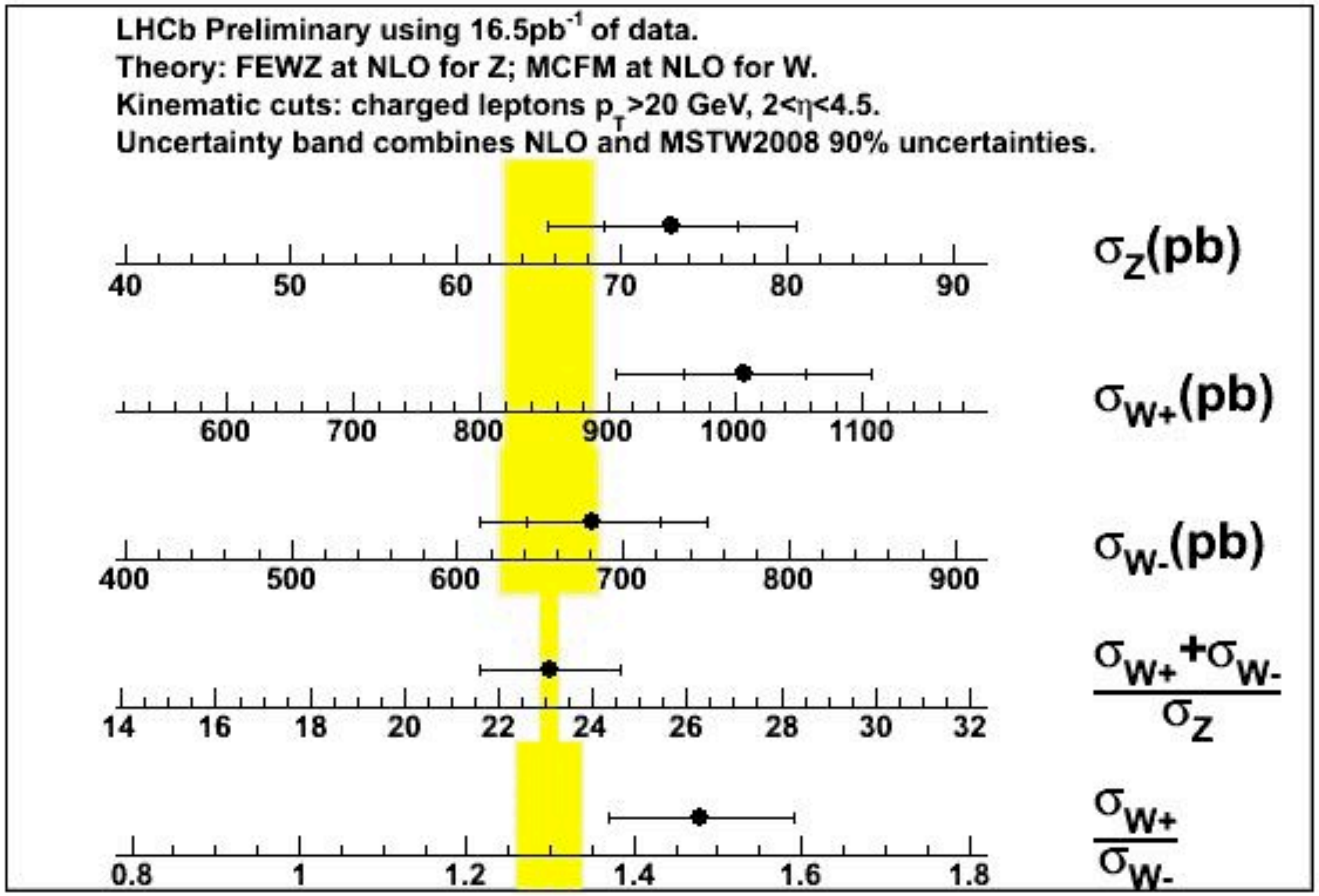
$A_W(\mu)$ $W^{+/-}$ asymmetry for muons



$\sigma_{W+} \cdot B(W^+\to\mu^+\nu;\ 2<\eta_\mu<4.5)=1007\pm48\pm100$pb

$\sigma_{W-} \cdot B(W^-\to\mu^-\bar{\nu};\ 2<\eta_\mu<4.5)=682\pm40\pm68$pb

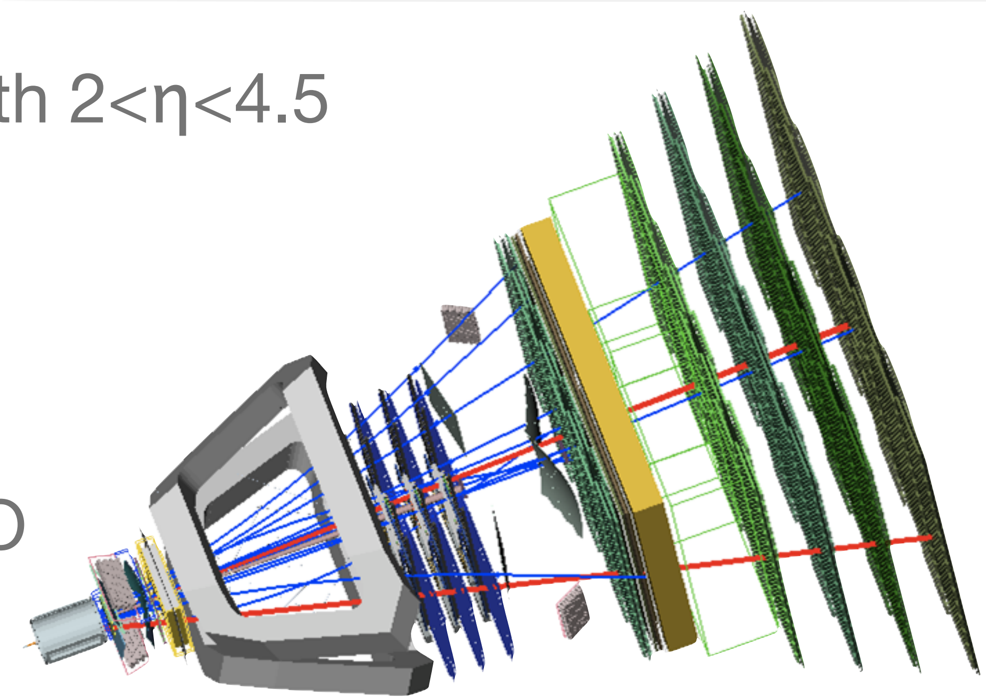
Comparison with current predictions



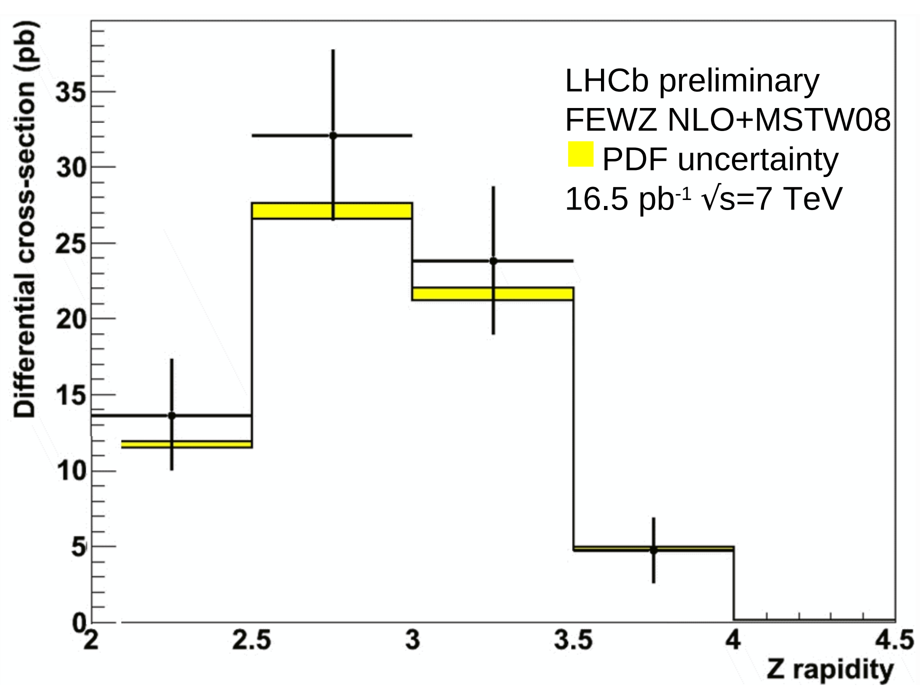
- LHCb data consistent with NLO theory

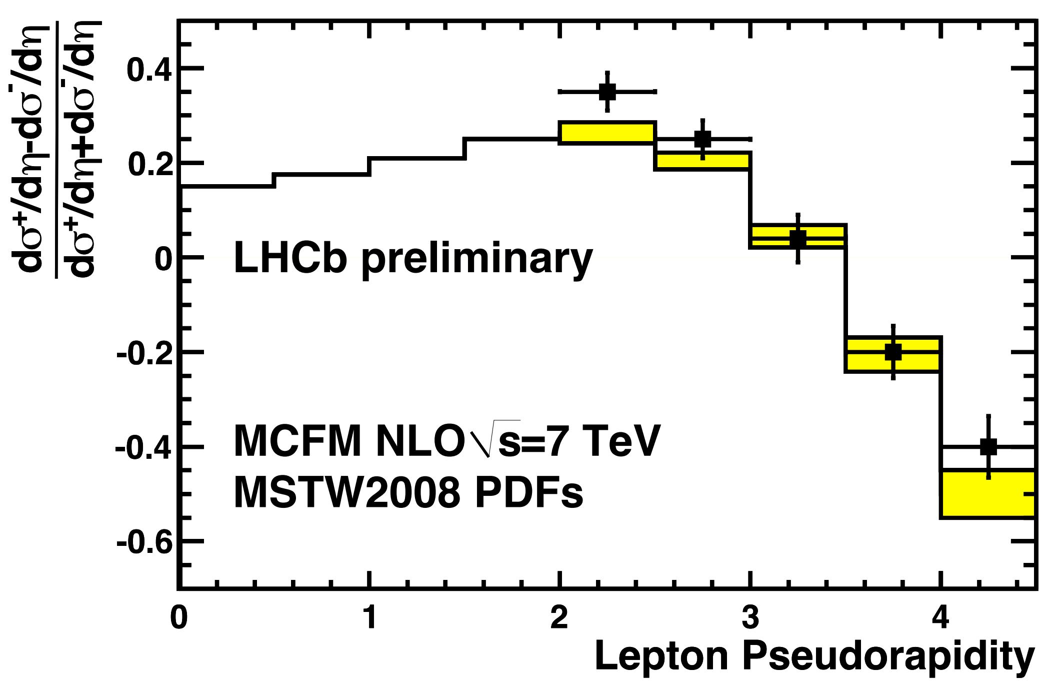
Summary

- Cross-sections for W and Z at 7TeV for muons with 2<η<4.5
- Probing proton PDFs in a new region of (x,Q^2)
- Results consistent with current predictions at NLO
- Expect to increase statistics dramatically in 2011 to 1-5fb^{-1}



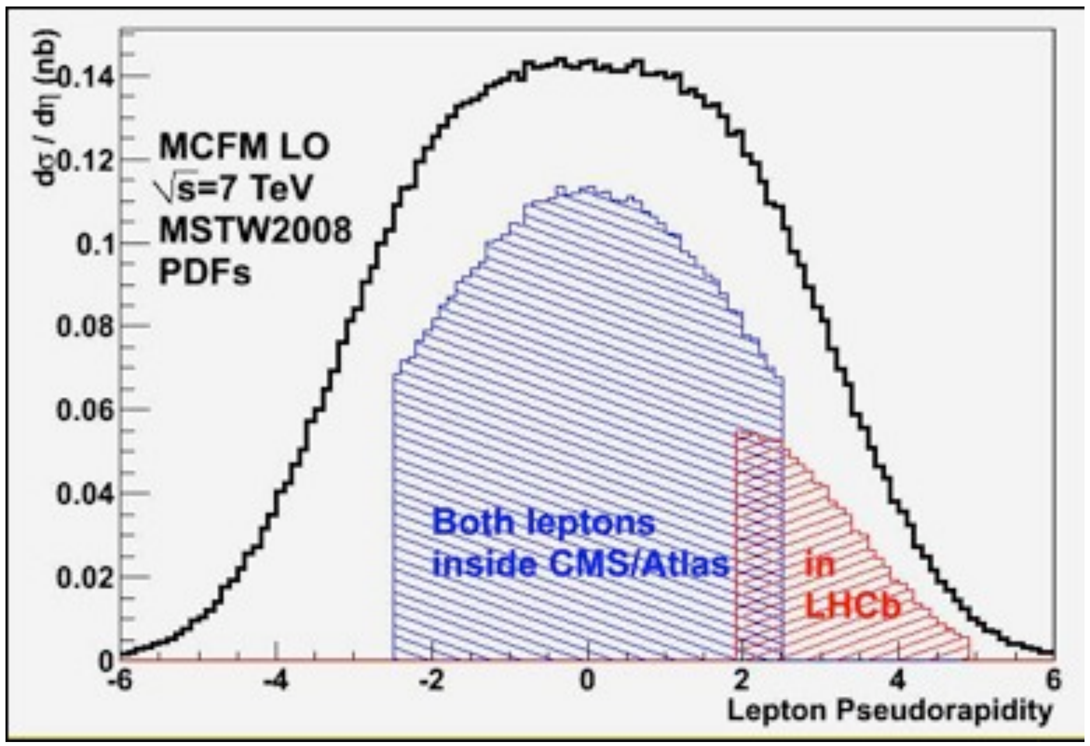
Z^0 candidate

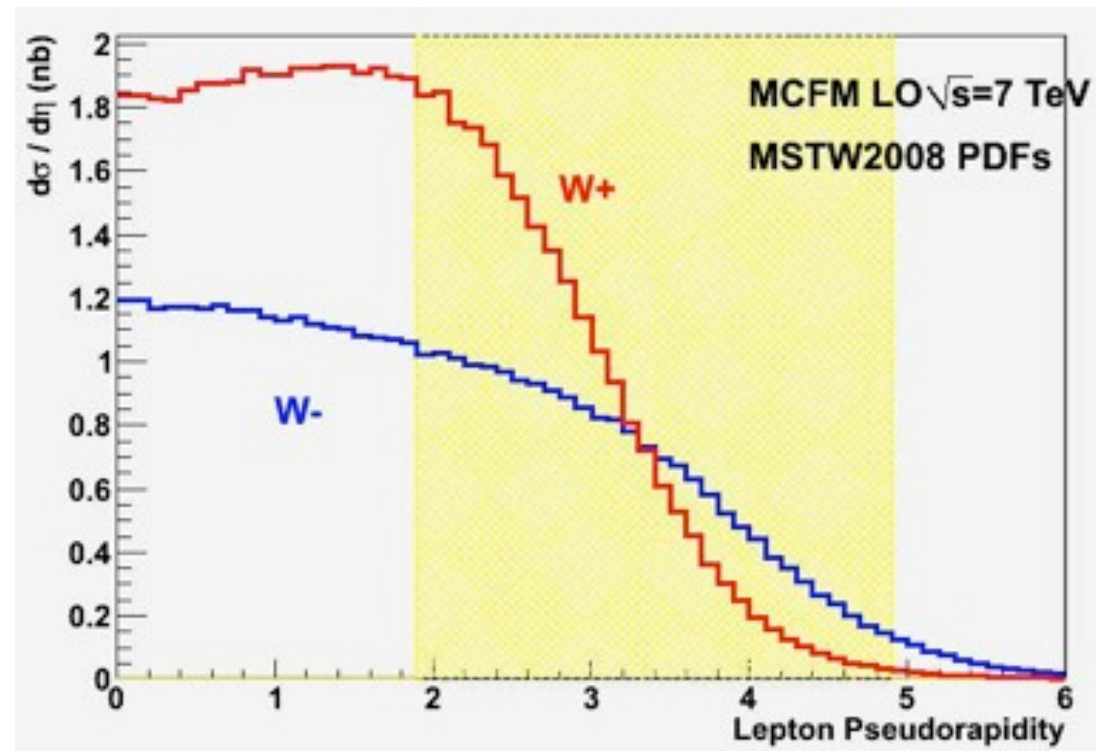




Backup

W & Z lepton pseudorapidity





8% of Z within LHCb acceptance

17% (16%) of W^+ (W^-) within LHCb acceptance

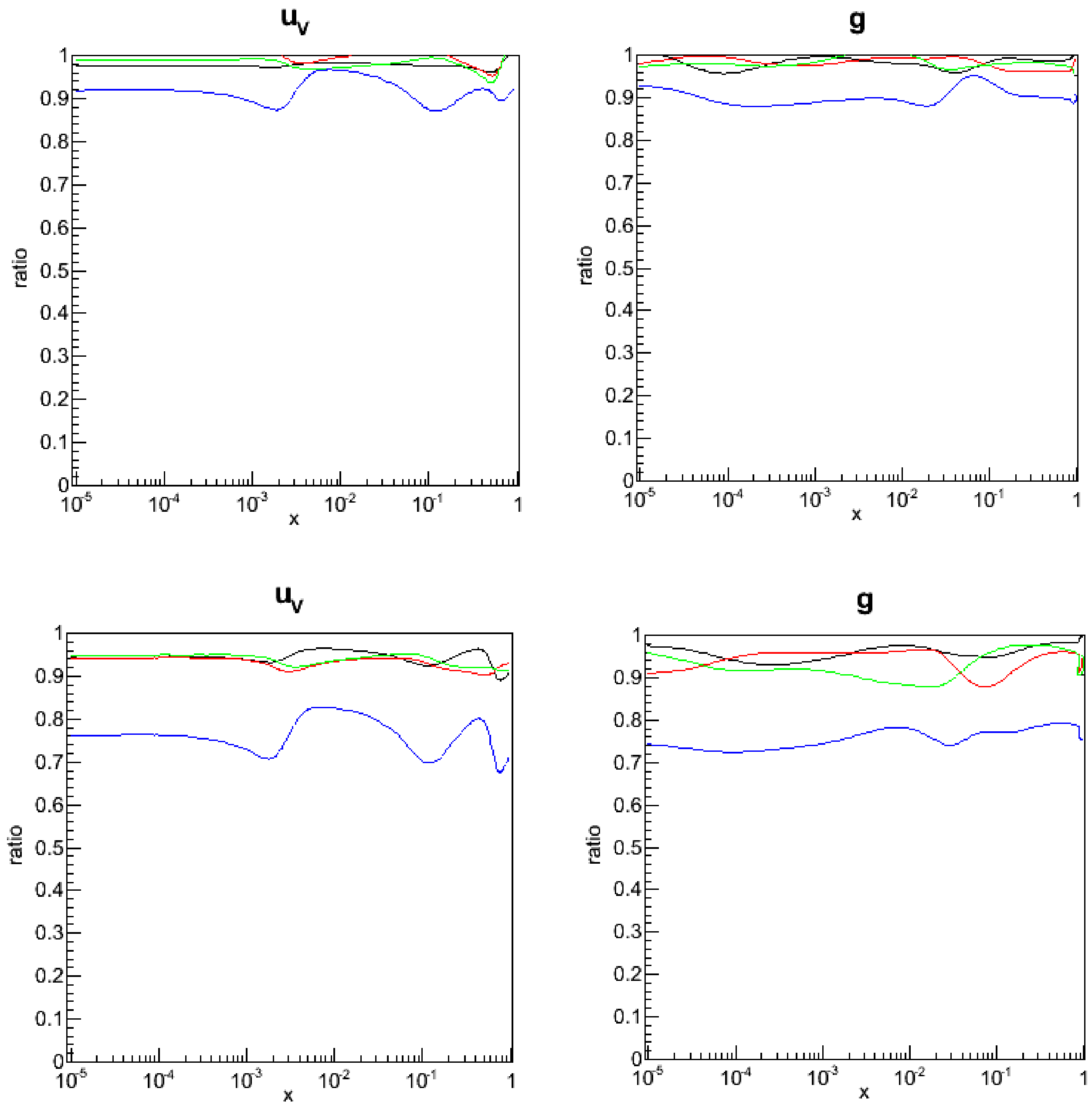
Systematic errors (%):

Source	σ_Z	σ_{W+}	σ_{W-}
Background	0.1	3	5
Trigger efficiency	1	1	1
Muon id efficiency	0.7	0.5	0.5
Track efficiency	4	4	4
Selection efficiency	n/a	2	2
Luminosity	10	10	10
Total systematic error	11	11	12
Stat. error	4	1	1

Largest source is luminosity uncertainty
Background: uncertainty large for W (shape variation in fit)
Efficiencies: statistical error on data-driven method

PDF sensitivity

Ratio = PDF uncertainty with LHCb data/
PDF uncertainty without LHCb data



- **Z**
- **W^+**
- **W^-**
- **W^+,W^-, & Z**

MSTW08 0.1fb^{-1}, 7TeV

Small data set - improvement ~10%

MSTW08 1.0fb^{-1}, 7TeV

Large data set - improvement ~30%

Further improvements at 14TeV

Tracking efficiency

Michel De Cian

LHCb-INT-2010-058

2.1 General Procedure

In the following the procedure to measure the tracking efficiency is described:

- Reconstruct a long track with $p_T > 20$ GeV, require that is has been positively identified by the muon system, and that it has triggered the event (i.e. the track is TOS[2]).
- Run a pattern recognition which reconstructs a standalone track in the muon system. Calculate the momentum of this standalone track by requiring it to have come from the primary vertex. Extrapolate the track through the TT detector and add hits which lie in a certain window around the track (at least 2 hits in the TT need to be found). Add these hits to the track and refit it. This track is subsequently called muonTT track.
- Require the muonTT track to have $p_T > 5$ GeV.
- Perform a vertex fit of the long track and the muonTT track.
- This can be done twice, as once the positively charged muon can be taken as ”tag”, once the negatively charged.
- Compare the LHCbIDs of the muonTT track with the ones of all the long tracks in the event with the same charge as the muonTT track. Apply a criterium for the number of LHCbIDs which have to match to call the track associated.

Muon ID efficiency

Tag + Probe

James Keaveney

Internal note in prep.

- μ ID efficiency is defined as the fraction of real muons which are reconstructed as long tracks that are subsequently matched to muon tracks and pass 'isMuon'

$$\epsilon_\mu = \frac{\text{true muon long tracks w/ isMuon==1}}{\text{true muon long tracks}} \quad (1)$$

- μ ID efficiency at the Z peak must be well understood as we proceed towards a σ·Br(Z $->\mu\mu$) measurement.
- The classic "Tag Probe method" is a suitable data-driven method to measure this efficiency.
- With $\approx$ 83 Z $->\mu\mu$ events in 1Pb^{-1} we are still statistically limited but enough Zs to test and tune the method.

Muon ID efficiency

Method

Tag+Probe methodology

- Tag -
  - Take all candidates from the stripping line Z02MuMuNoPIDs in $\approx 1Pb^{-1}$
  - Apply track pre-selections (P(χ^2), σP/P)
  - Apply tight μ ID to one of the muons, (isMuon==1, PIDmu> -3)
  - require surviving candidates to have $75GeV < M_{\mu\mu} < 107GeV$. (Close to Z peak)
- Probe -
  - The fraction of these candidates in which the unbiased muon passes isMuon==1 estimates the single muon efficiency.
  - From this we deduce the dimuon ID efficiency $\epsilon_{\mu\mu} = (\epsilon_\mu)^2$

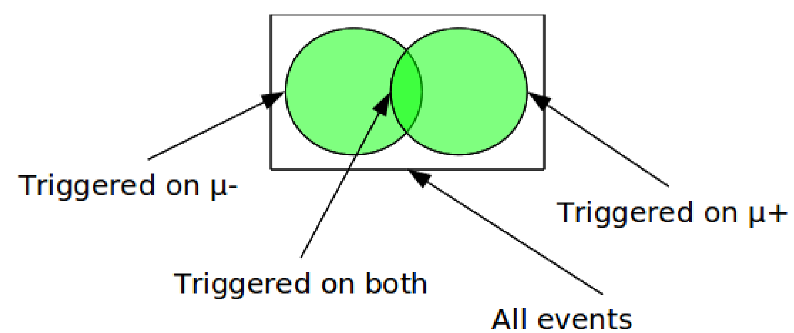
Trigger efficiency

University of Zurich[UZH]

Physics Institute

Albert Burshe

Method



$$
\begin{aligned}
\varepsilon^{+} &= n_{+\wedge-}/n_{-} && (1)\\
\varepsilon^{-} &= n_{+\wedge-}/n_{+} && (2)\\
\varepsilon^{-\vee+} &= \varepsilon^{+}+\varepsilon^{-}-\varepsilon^{+}\varepsilon^{-} && (3)\\
\varepsilon^{\text{at least one muon TOS}} &= \varepsilon+\varepsilon-\varepsilon\varepsilon = 2\varepsilon+\varepsilon^{2} && (4)\\
\varepsilon^{\text{both muons TOS}} &= \varepsilon^{2} && (5)\\
\frac{n_{\text{both muons TOS}}}{n_{\text{at least one muon TOS}}} &= \frac{\varepsilon^{2}}{2\varepsilon+\varepsilon^{2}} =: \gamma && (6)\\
\varepsilon &= \frac{2\gamma}{\gamma+1} && (7)
\end{aligned}
$$

MSTW 2008 NLO PDFs (68% C.L.)